11 September 1969

MEMORANDUM

To:

Subj: Information to Supplement Proposal

I.   Task Abstract

calls for a continuation of the program of research in computerized image processing for a period of twelve months. Primary emphasis will be placed on experimental determination of the extent to which image processing increases the extraction of information from noisy degraded images. Effort will also be directed toward the problem of spatial non-linearity. Mathematical modeling of the adjacency effects will be undertaken with experimental data from realistically chemically processed film used as a basis for determining the constants in the analytic model.

The Visibility Laboratory has been conducting, under funding from the Central Intelligence Agency   , a continuing program of research in the restoration of degraded photographic images by means of computer processing. Funding in response to Proposal   covered a 3-month period ending 1 July 1969. Funding in response to Proposal   covered a 3-month period ending 30 September 1969. The present proposal calls for a continuation of the effort during the period 1 October 1969 to 30 September 1970. The following is a brief description of the status of the several tasks which have received effort in the course of this research program.

Task I: On-Line Computer Operation. The research program utilizes an IBM-1800 computer which is leased with the cost equally shared by the Central Intelligence Agency and the Advanced Research Projects Agency. The Visibility Laboratory sometimes finds it efficient to utilize time on the IBM-1800 when available, for work on other Laboratory contracts or grants. When this is done, the appropriate cost of that time is recharged to the contract or grant involved.

Substantial progress has been made in achieving flexible and efficient software for performing the image processing research. The utilization of the computer has been dramatically increased by the development of an unattended night operation in which the computer receives its instructions from cards rather than the keyboard. The instructions are still given in the language of image processing, and techniques have been developed such that the cards are easy to prepare.

The unattended card mode of operation has been supplemented by the addition of a 35 mm Automax camera whose shutter and film advance mechanisms are computer controlled. This allows pictures to be made during all night runs.

A very recent development tremendously enhances the ability to make parametric studies in the unattended mode of operation. In a parametric study, there is usually a sequence of operations which is repeated many times with one or more important parameters incremented during each repetition. The new software allows the operator to advise the computer that he desires the computer to memorize a sequence of operations which he then enters. He also indicates the starting values and increments for each parameter and the number of times the sequence is to be run. In this way a very small number of cards of instructions, taking only minutes to prepare, is all that is required to handle calculations lasting many hours. Coupled with the Automax camera, runs involving 40 hours of computation and producing 600 output pictures have already been made.

Within the last several months a new form of array indexing has been implemented in the software resulting in reduction in time by factors of 25 to 50% depending on the nature of the specific operation involved. Increased use of the computer sense and data switches has also been achieved. These switches are used to make routine decisions, as for example, is a gamma other than unity to be introduced into a displayed picture? There are now 13 such switches in use resulting in a substantial reduction in the time required for typewriter communication.

Task 2: Equipment Engineering: Under the present funding, effort has been directed toward improved display capability. As explained in Proposal 18 April 1968, the level of funding provided in response to that proposal did not permit full exploitation of the concepts of improved display systems which have evolved during the course of the research. Nevertheless, the recirculating or refresh display system has been achieved. In this equipment, an image can be loaded into a small core memory which is an integral part of the display unit. This core memory is then scanned repetitively at TV type rates and displayed on a cathode-ray-tube for direct viewing. This provides a flicker-free presentation not requiring photographic recording. An exploratory unit was constructed and tested.

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Supplementary circuitry has been constructed for the refresh display which provides what is called inner-raster-scan. The inner-raster-scan reduces the distracting discreteness of the displayed images by spreading the flux from a single data point over the region between data points in a controlled way. The particular weighting of the flux distirbution is programmable. It is presently being operated in a mode which is equivalent to providing two-dimensional linear interpolation between data points. Preliminary results show substantial improvements in the appearance of the images. The inner-raster-scan is presently operable in a slow scan photographic recording mode because the circuitry will not allow the high scan rates which would be required for the direct view mode of operation.

Testing and repackaging of the refresh display has been completed. Final incorporation into the computer system is now in progress.

Other equipment developments are being funded by the Advanced Research Projects Agency. Although they are not being paid for by the Central Intelligence Agency, they will be used for the Central Intelligence research program at the Visibility Laboratory. These equipments include an image dissector film scanner and a microscope flying spot scanner. The image dissector now exists in breadboard form and the microscope flying spot scanner is now under construction. These all-electronic scanners offer the advantage of putting the film scanning operations under computer control so that the operator can position the scan and choose the step size and array size at will. During these operations the scanning will be at TV rates to provide direct viewing on a c. r. t. display. The scan speed would be reduced for actual data taking to maximize the signal-to-noise ratio.

Task 3: Basic Restoration Investigation: The basic theoretical and experimental studies of optimum restoration techniques have been continued. Exciting progress has been made in non-Fourier techniques of image processing. These explorations have included extensions of the non-negative algorithm previously described, the application of linear programming, and an algorithm involving Baye's theorem. Each of these techniques have the inherent ability to utilize a'priori constraints on the image restoration, as for example, boundaries on the object of interest, and non-negative luminance or brightness values. Preliminary studies have produced results which appear, in some cases, to be considerably better than Fourier processing of the same images. All three techniques are at present, time consuming with respect to the Fourier techniques.

Defocus degradations have received considerable attention. Laboratory photographs intentionally defocussed have been scanned and successfully restored. These first experiments have involved large amounts of defocus, i. e., low resolution photography where the film granularity situation is favorable. Experimental

studies of defocus point spread functions for a NIKON camera have been made and it has been found that results are not in agreement with general defocus theory reported in the open literature. Explanations of this discrepancy have been postulated and are now being tested. Since the effect of this discrepancy would be greatest for small amounts of defocus and with high resolution, it is important to resolve this discrepancy prior to attempting image restoration on high resolution photography.

Image motion studies are presently underway. Restorations have been successfully performed on low resolution photography. High resolution restoration experiments will be made in the near future.

A technique known as "sanding" has been developed. This technique is based on the realization that when an image is degraded, the spatial derivatives of the image are reduced. A high value for a spatial derivative in a degraded image is probably due to film granularity or film defects such as dust, scratches, etc. The sanding operation explores the spatial deritives and alters data values to restrain the derivatives to any specified limit. Further effort is required to determine the capabilities and limitations of this technique.

Considerable emphasis was placed on a study designed to show the reasonable expectations for image processing. In this study, best-least-square filtering was performed on images which had been subjected to defocus degradation on the computer and in which multiplicative noise had been introduced. The two parameters of the study are amount of defocus and noise level. Both parameters were varied over a range which well covers all imagery of interest. The output from the study is an array of pictures (before and after) which show the level of image improvement which can be expected. The first set of pictures has been obtained. The study is still in progress. The computer runs will be repeated for several objects and will also be repeated using various techniques of background suppression.

Task 4: Dual Gamma Studies: The dual gamma studies have been in progress for several months. The initial effort was directed toward the development of a mathematical model of the process. The first model explains the adjacency effect on the basis of a granular visualization in which (a) there is a limited amount of developer present, (b) the number of grains developed in an increment of time is proportional to the quantity of developer available at that point, and (c) the developer has some limited amount of lateral mobility so that small area shortages in developer are resupplied from adjacent developer whereas large area shortages cannot be so resupplied.

The first simple mathematical model has been programmed on the computer in such a way that "latent images" can be subjected to this model of chemical processing. To date variable width bar images and a picture of the Capitol Building have been processed in this way. The adjacency effect is evident in the bar imagery. It is apparent that the extent of the adjacency effect is dependent on the spatial density gradients in the image. A badly degraded image has reduced spatial density gradients and therefore reduced adjacency. Fundamental data is needed to allow adjustment of the constants in the model in order to achieve results which are comparable with real dual gamma imagery. The resulting models and the experimental data itself will be used to determine the extent to which the present image processing techniques limited in their application to high resolution photography by virtue of the spatial non-linearity effects. Processing experiments will be continued with emphasis on determining optimum filters based on measured visual performance in tasks involving information extraction.

II   Introduction

General Background: The Visibility Laboratory has been conducting under funding from the Central Intelligence Agency (   ) a continuing program of research in the restoration of degraded photographic images by means of computer processing. Funding in response to Proposal covered a 3-month period ending 1 July 1969. Funding in response to Proposal covered a 3-month period ending 30 September 1969. The present proposal calls for a continuation of the effort during the period 1 October 1969 to 30 September 1970. The following is a brief description of the status of the several tasks which have received effort in the course of this research program.

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Task 4: Dual Gamma Studies: The dual gamma studies have been in progress for several months. The initial effort was directed toward the development of a mathematical model of the process. The first model explains the adjacency effect on the basis of a granular visualization in which (a) there is a limited amount of developer present, (b) the number of grains developed in an increment of time is proportional to the quantity of developer available at that point, and (c) the developer has some limited amount of lateral mobility so that small area shortages in developer are resupplied from adjacent developer whereas large area shortages cannot be so resupplied.

This first simple mathematical model has been programmed on the computer in such a way that "latent images" can be subjected to this model of chemical processing. To date variable width bar images and a picture of the Capitol Building have been processed in this way. The adjacency effect is evident in the bar imagery. It is apparent that the extent of the adjacency effect is dependent on the spatial density gradients in the image. A badly degraded image has reduced spatial density gradients and therefore reduced adjacency. Fundamental data is needed to allow adjustment of the constants in the model in order to achieve results which are comparable with real dual gamma imagery.

Scope of Work: The proposed program of research is based on a careful study of the status of image processing and an attempt to define the research goals which will, at the end of the year's effort, maximize knowledge of the ultimate capabilities and limitations of image processing for practical applications. The specific tasks proposed are as follows:

Task 1:   Information Extraction Experiments.   The goal of the image processing research at the Visibility Laboratory is the development of techniques of image manipulation such that an observer is able to extract more information from the processed picture than he is able to extract from the original unprocessed picture.   The merits of image processing are determined largely by the extent to which increased information extraction actually occurs.

Subjective judgements as to the success of a processing operation cannot properly grade success in information extraction improvement since a processed image may be less pleasing to the eye yet allow increased information extraction or vice versa.   It is, therefore, proposed that a set of noisy degraded images be generated in which there are a restricted number of object alternatives.   Amount of degradation and noise level will be the variable parameters of the experiment.   Observers will be called upon to go through these decks and make decisions as to which object is present.   The output data will be probability of correct decision as a function of the amount of defocus and noise level.

The same image decks will now be computer processed and the observer tests repeated yielding a new set of probability of correct decision curves.   A comparison of the two sets of curves gives a quantitative measure of the improvement in image information extraction.

The experiments must be repeated a number of times using a variety of object types in order to see the effect of object type on the results.   The experiments will be performed using both naive observers, i. e., untrained in photographic information extraction, and experienced observers.

The results of these experiments provide a foundation upon which the practical application of image processing may be judged.   For any specific application image processing must be judged by weighting the extent of the information extraction improvement, the frequency of occurence of this class of degraded noisy images, and the cost and time associated with the processing.

Task 2:   Modeling of Spatial Non-Linearities: The existence of spatial non-linearity, i. e., adjacency effects, imposes a limitation on the linear processing of degraded imagery.   The nature of these limitations must be determined. Adjacency effects result from chemical processing.   For high resolution imagery great care and elaborate processing mechanizations are required to minimize the effects.   Since the Visibility Laboratory is not equipped to perform this type of chemical processing, we cannot generate appropriate materials to study the problem experimentally.

For this reason, the starting point for this task will be to accumulate meaningful adjacency data from experiments performed elsewhere. Using this data, analytic modeling of the effect will be accomplished. In the case of a non-linearity, analytic modeling is an important tool because the spatial non-linearity means that the observed results are object dependent and, therefore, the experiments must be repeated for each new object. In computer studies, the spatial non-linearity can be cleanly separated from problems of film granularity and applied to a wide variety of object types in a short period of time provided that an adequate analytic model of the process has been developed. It is not at all necessary that the model have high precision in order to achieve the desired results.

III.　　Technical Discussion

The program of research which is proposed is chosen to be that which, at the end of one year's time, will yield maximum output in terms of providing fundamental answers to the most basic questions with respect to the practical application of image processing. No new research equipments will be developed under the funding from this proposal.

A critical examination has been made of the state-of-the-art of image processing. An attempt was then made to determine the principal questions which must be answered in order to allow a realistic determination of the extent to which image processing will be useful in practical applications of interest. The primary questions are as follows:

(a) Assuming the absence of spatial non-linearities, i. e., adjacency effects, to what extent does image processing actually increase the human observers capability for information extraction?

(b) Based on reliable data from photographic films chemically processed under operational conditions, to what extent does the spatial non-linearity which is present limit the application of the linear processing techniques which have been developed?

(c) If the answer to question (b) is that the limitations due to spatial non-linearity are significant, what alternatives are available to minimize or eliminate this problem?

(d) In addition to spatial non-linearity, are there other properties of operational imagery which limit the application of the techniques which have been developed.

The specific tasks proposed in response to these questions are as follows:

Task I: Information Extraction Experiments.   The goal of the image processing research at the Visibility Laboratory is the development of techniques of image manipulation such that an observer is able to extract more information from the processed picture than he is able to extract from the original unprocessed picture.

The human visual system has remarkable capability for information extraction.   The state-of-the-art of modeling of the eye-brain combination does not permit calculation fo human visual system performance in general information extraction tasks.   For this reason quantitative information can only be obtained experimentally.   Under this task, such experiments will be performed both on un-processes and processed imagery to determine quantitatively the improvement in information extraction provided by image processing.

A set of noisy degraded photographic prints will be generated in which there are a restricted number of object alternatives.   The amount of degradation and noise level will be the variable parameters of the experiment.   Observers will be called upon to go through these image decks and make decisions as to which object is present.   The output data will be the probability of correct decision as a function of the amount of defocus and noise.

The same image decks will now be computer processed and the observer tests repeated yielding a new set of probability of correct decision curves. A comparison of the two sets of curves gives a quantitative measure of the improvement in image information extraction.

The choice of object alternatives for these testw will present some difficulty.   It will undoubtedly be necessary to repeat the tests for a variety of object selections.   One such run will be made using alphanumeric characters.   The alpha-numeric characters are desirable for the same reasons that they are used in vision testing.   They represent well known objects requiring no learning and the results provide a stable baseline for comparisons.   Other more realistic objects will be used in addition to the alphnumerics.

The first tests will be made using Visibility Laboratory observers.   These observers must be classed as naive with respect to information extraction from photographic images.   After these test results are obtained, the image decks should then be passed along to experienced photo interpreters and their scores recorded. At this point in the experiments it would be expected that the photointerpreters could supply valuable feedback with respect to suggested changes in object alternatives in order to make the tests more realistic.

The results of these experiments provide a foundation upon which the practical application of image processing may be judged.   For any specific application, image processing may be judged by weighting the extent of the information extraction improvement, the frequency of occurence of this class of degraded, noisy imagery, and the cost and time associated with the processing.

Task 2: _Modeling of Spatial Non-Linearity:_   The existence of spatial non-linearity, i. e., adjacency effects, imposes a limitation on the linear processing of degraded imagery. The nature of these limitations must be determined. Adjacency effects result from chemical processing. For high resolution imagery great care and elaborate processing mechanizations are required to minimize the effects. Since the Visibility Laboratory is not equipped to perform this type of chemical processing, we cannot generate appropriate materials to study the problem experimentally.

For this reason, the starting point for this task will be to accumulate meaningful adjacency data from experiments performed elsewhere. Using this data, analytic modeling of the effect will be accomplished. In the case of a non-linearity, analytic modeling is an important tool because the spatial non-linearity means that the observed results are object dependent and, therefore, the experiments must be repeated for each new object. In computer studies, the spatial non-linearity can be cleanly separated from problems of film granularity and applied to a wide variety of object types in a short period of time provided that an adequate analytic model of the process has been developed. It is not at all necessary that the model have high precision in order to achieve the desired results.

Task 3: _Study of Spatial Non-Linearity Limitations._   The purpose of this study is to utilize both experimental evidence and the analytic modeling from Task 2 to determine the extent to which spatial non-linearity imposes limitations upon the ability to apply the image processing techniques to high resolution photography. Important parameters of this study will include image size, object size, object contrast, and the magnitude of the image degradation. Using the results of the analytic modeling, the images of Task I will be subjected to the spatial non-linearity and before and after performance tests performed to determine the extent to which information extraction is altered.

There are many possible outcomes from these studies. For example, it may be shown that, (a) spatial non-linearity does not seriously limit the application of present processing techniques, (b) spatial non-linearity severely limits the application of present techniques, (c) other techniques can be developed to minimize the effect of spatial non-linearity during computer processing, (d) better chemical processing techniques will be required if image processing is to be successfully applied.

Task 4: _Continuation of Processing Experiments:_   The processing experiments including the development of optimum filters will be continued. These experiments involve the scanning, digitizing, and computer manipulation of real degraded photographic imagery. As higher resolution photography is used, it will be necessary to obtain films chemically processed elsewhere for the reasons outlined in Task 2 and 3. While Visibility Laboratory chemically processed imagery will suffice for some studies, emphasis will be on computer processing of imagery at high resolution and with chemical processing that represents the state-of-the-art.

IV.   Work Statement

Task 1: Information Extraction Experiments:

1. Generate picture card decks having noisy degraded images and perform visual psychophysics tests to determine the probability of correct decision as a function of amount of degradation and noise using Visibility Laboratory observers.

2. Computer process the images of subtask 1 and repeat the experiments using Visibility Laboratory observers.

3. Repeat the experiments of subtasks 1 and 2 using trained photo-interpreters.

4. Generate new picture decks using different object alternatives as suggested by the experimental results and/or suggestions of the photointerpreters and repeat experiments.

5. Analyze the results of the tests in terms of there implication as to the value of image processing for information extraction.

Task 2: Modeling of Spatial Non-Linearity:

1. Obtain data on spatial non-linearity from organizations capable of performing state-of-the-art chemical processing.

2. Develop simple analytic models of adjacency and fit the data from subtask 1 by adjusting the constants in the model.

Task 3: Study of Spatial Non-Linearity Limitations on Image Processing:

1. Perform computer studies on computer degraded images subjected to spatial non-linearity by means of the analytic models developed in Task 2, subtask 2. Determine the extent to which the spatial non-linearity prevents the use of the linear processing techniques.

2. Study the possibilities for modifying the image processing techniques to minimize the adverse effects of spatial non-linearity.

Task 4: Continuation of Processing Experiments:

1. Continue the study of optimum filtering for the case of unknown objects degraded by defocus and/or image motion.

2. Obtain degraded photographic imagery from sources able to achieve state-of-the-art chemical processing and perform image processing studies. At least some of this imagery should involve the same object alternatives used in Task 1.

3. Perform visual psychophysics experiments on the processed and unprocessed images of subtask 2.

V. Deliverable Items

1. Oral reports on this work should be made in Washington at times to be agreed upon by both parties. These should include reports at the conclusion of Task 1, Task 3, and a final report at the conclusion of the year's effort.

2. There is no deliverable equipment associated with the work described in this proposal.

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VI.

Performance Percentage Completion

Task	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
	7	14	22	26	35	44	52	65	76	84	94	100
1	3	6	9	9	9	9	9	9	9	9	9	9
2	3	6	9	9	9	9	9	9	9	9	9	9
3			1	1	1	1	1	1	1	1	1	1
4			1	1	3	6	6	9	12	12	14	14
5					1	2	3	3	4	5	6	7
Task 2												
1			1	2	3	4	5	6	6	6	6	6
2				1	2	3	4	4	4	4	4	4
Task 3												
1				1	1	3	4	4	6	8	8	10
2							2	2	4	6	8	10
Task 4												
1		1	2	3	4	5	7	8	9	10	11	12
2					1	3	5	7	8	9	10	11
3							1	3	4	5	6	7

VII

Time Bar Chart

- 15 a -

Task	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
1	X	X	X	X								
2	X	X	X	X	X	X						
3				X	X	X		X	X	X	X	X
4					X	X						
5			X		X	X	X	X	X	X	X	X
Task 2												
1		X		X	X	X	X	X				
2				X	X	X	X	X	X	X	X	
Task 3												
1							X	X	X	X	X	
2						X	X	X	X	X	X	
Task 4												
1	X	X	X	X	X	X	X	X	X	X	X	X
2					X	X	X	X	X	X	X	X
3							X	X	X	X	X	X